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Student's Misconceptions on the Concept of Chemical Equilibrium

Öğrencilerin Kimyasal Denge Konusundaki Kavram Yanılgıları

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Abstract

The purpose of this study was to determine students' misconceptions regarding the concepts of chemical equilibrium. To diagnose students' misconceptions in this area, a written test was administered to 216 11th grade high school students after their formal class schedule. The original test was developed by Hackling and Garnett, 1984 and translated and adopted into Turkish by the authors. The test included 47 multiple choice and true-false items and its reliability coefficient was found to be 0,87. An interview was also conducted with 20 students to establish their reasons for misconception with the open-ended questions. Analysis of responses revealed widespread misconceptions among students in the areas related to (1) approaches to chemical equilibrium, (2) characteristics of chemical equilibrium, (3) changing chemical equilibrium conditions, and (4) adding a catalyst.

Keywords: Chemical equilibrium, misconceptions, chemistry education.

Öz

Bu çalışmanın temel amacı, öğrencilerin kimyasal denge ile ilgili kavram yanılgılarını belirlemektir. Öğrencilerin bu konudaki yanlış kavramlarını tespit etmek için, hazırlanan bir test, 216 lise üçüncü sınıf öğrencisine, konu sınıfta anlatıldıktan sonra uygulanmıştır. Testin orijinali Hackling and Garnett tarafından 1984 yılında geliştirilmiştir. Bu test Türkçeye çevrilmiş ve yeniden gözden geçirilerek Türkiye şartlarına uyarlanmıştır. Test doğru- yanlış ve çoktan seçmeli sorulardan oluşmuş ve güvenirlik katsayısı 0,87 olarak hesaplanmıştır. Ayrıca, öğrencilerin kavram yanılgılarının nedenlerini anlamak için 20 öğrenci ile mülakat yapılmıştır. Cevapların analizi, öğrencilerin şu konularda yaygın olarak yanlış kavramlara sahip olduğunu göstermiştir: (1) Tepkime dengeye gelirken, (2) kimyasal dengenin özellikleri, (3) kimyasal denge koşullarının değiştirilmesi ve (4) katalizör ilavesi.

Anahtar Sözcükler: Kimyasal denge, kavram yanılgıları, kimya eğitimi.

Introduction

Recently, science educators have focused their attention on how students learn and the factors which influence their learning. Learning is the interaction between what the student is taught and his current ideas or concepts. It is not acceptable to assume that students simply absorb information about scientific phenomena (Linn, 1987). They are continually figuring out new information using their knowledge of the field. A central goal of education is for students to be able to teach themselves and improve their own knowledge. This is possible with higher order thinking skills. In other words, comprehension, solving problems and inquiry skills are required rather than memorizing. In order to let students gain these skills, the role and competency of teachers are very important. Gürçay, Bozkurt, Kaptan and Berberoglu (2000) developed a Science Academic Qualification Test and administered it to 222 student teachers from different universities in Turkey. They

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found that student teachers' success in higher order thinking skills was less than %50. These results showed that teacher education programmes in science education need to put more emphasis on teaching activities to improve teachers and student teachers' higher order thinking skills. According to high school teachers, high school curricula focus more on covering content than on developing understanding. Demirci (2000) developed a questionnaire which is related to the productivity of chemistry lessons and administered it to 970 high school students from different grades. His investigation included two parts. First, he identified students' difficulties with chemistry topics. Students found the following subjects to be easy: moles, solubility, gases, chemical calculations etc. Examples of difficult subjects are: oxidation and reduction reactions, radioactivity, acid and bases, chemical equilibrium etc. Second, to determine the productivity of chemistry lessons, he asked two questions from each subject considered easy and difficult by students. Analysis of the results showed that productivity of chemistry subjects was very low for difficult subjects and that, even though students assumed that some of subjects were easy, they did not have enough knowledge in those subjects. The researchers claim that this result comes from students' memorization of some concepts without understanding them.

There is an important connection between what teachers think and what they do. Clark and Peterson (1986) state that there is a reciprocal relationship between teacher thought and teacher action. A teacher's thought includes teachers' theories and beliefs, planning and interaction, thoughts and decisions, while teacher action and its observable effects include teacher's classroom behaviour and students' classroom behaviour and achievement. According to Heron (1996) some students, despite being perfect, kind and considerate, hardworking and anxious to learn do not learn and instead memorize chemical symbols and describe events seen in the laboratory. If teachers set up a problem involving moles, students get the answer but they do not understand what teacher is doing when teachers translate a chemical equation into a mathematical statement because teachers introduce concepts and subjects that are tied together in the learner's mind but fail to promote information about how they are connected with each other (Steward, 1979). This encourages students to memorize words and use algorithms to solve numerical problems without completely understanding the underlying scientific concept.

Teachers are regarded as the authoritative experts, the main sources of knowledge and the focal point of all activities in our country. The students are the passive recipient of information already acquired by the teacher but most of the educators agreed that knowledge is not transmitted from one person to another; it is constructed by each learner as a result of interactions with reality and negotiations of meaning with other people.(Bodner, 1986; Hewson, P.W. and Hewson, M. G., 1988). Inappropriate teacher strategies and learning activities provided by teachers can cause misconceptions in science.

Many studies deal with students' conceptions different from those accepted as correct by experts. Scientists have given several names to these alternative views including "alternative frameworks" (Driver and Easley, 1978), "children's science" (Osborne, Bell and Gilbert, 1983) and "misconceptions" (Griffiths and Preston, 1992). Researchers have been using the term misconception for most of those alternative conceptions that result from life experience, experiential misconceptions and instructional misconceptions arrived at through the process of instruction. Experiential misconceptions occur before instruction takes place. They result from a logical interaction of students' sensory data, with its inherit limitations. They are resistant to change. Students may acquire instructional misconceptions through either formal or informal instruction. Those misconceptions arise from the following reasons: the choice of mental strategies may be inappropriate to the subject matter; and students' deficient prior knowledge, misunderstanding and symbols, short term memory and low cognitive development (Kathleen, 1994).

Most of the students' misconceptions regarding chemical phenomena generally are not experiential because the existence of atoms and molecules is not directly encountered within the realm of everyday experience. Misconceptions relating to those more abstract phenomena result from some instructional experience, within or outside of the classroom, but chemical equilibrium presents particularly unique opportunities for misconception in both of the categories. In one disheartening study (Quilez and Solaz, 1985), high school teachers showed extensive misunderstanding of the concepts of chemical equilibrium. It has been said that experiential misconceptions occur in connection with phenomena encountered in everyday experience. For example, students usually use the everyday meaning of the word 'equilibrium' synonymously with the chemical meaning. This leads them to think of chemical equilibrium as static rather than dynamic. On the other hand, prior knowledge, language and cognitive development can be the cause of misconceptions related to instructional process. A learner's prior knowledge is the most important variable in success in learning science. If the students' prior knowledge is not enough to process new information, they will become confused, reason inaccurately, and eventually form a misconception. Therefore, teachers need to take into account students' prior knowledge before instruction takes place and include this in solutions. The other source of misconception related to instructional process is the use of language in teaching. This is important because the language used by the teachers to communicate concepts may cause students to misinterpret vocabulary, symbols, terms and analogies. For example, all of the terms below used for the description of equilibrium systems can cause great confusion; left, right, stress, shift, favor, forward, reverse, etc. Kathlen (1994) found that while interviewing students on their representation and studies of typical equilibrium problems, some students interpreted the term "favored reaction" to mean that the reactants for the favored reaction remained as reactants, rather than they were "favored" to be converted to products. Also, "K" is sometimes used to represent the solubility constant, equilibrium constant and weak acid and bases constant; "m" is used to represent meters and mass; "M" represents both molar mass and molarity; and "n" represents the number of moles, whereas "N" stands for the number of objects in a mole as well as normality, a term confusing enough in its own right. Therefore, a teacher must clarify frequently and get feedback from students with regard to their understanding of the meaning of various symbols and terms.

Another cause of misconceptions related to the instructional process is students' cognitive development. If teachers use knowledge which is already organized, they are attempting to transmit a fully organized set of ideas. However, the students have not yet created an organization for themselves and cannot receive the information intact. On this point, teachers need to consider students' cognitive development and whether students have understood the concepts or not before doing many problem solving activities. Therefore, teachers need to develop ways to promote students' conceptual understanding and to facilitate learning rather than to control it.

There are different methods available to identify students' misconceptions. The most common one is the interview technique. Researchers used this technique to study misconceptions of students in chemical equilibrium (Bergguist and Heikkinen, 1990; Hackling and Garnet, 1985) in stoichiometry (Mitchell and Gunstone, 1984) and in solutions (Ebenezer, 1995). The other technique is multiple-choice tests. Researchers have developed and administered misconception identification tests related to chemical equilibrium (Voska and Heikkinen, 2000; Quilez and Solaz, 1995; Banerjee and Power, 1991; Wheeler and Kass, 1978) and related to covalent bonding and chemical structure (Treagust, 1988).

Many researchers have found that chemical equilibrium is one of the important and difficult topics in science content to teach (Bergguist and Heikkinen, 1990 and Camacho and Good, 1989). Understanding chemical equilibrium concepts influence understanding of further concepts such as acid base behaviour, oxidation/reduction reactions and solubility (Bergguist and Heikkinen, 1990). The concept of chemical equilibrium includes synthesis of most general chemistry concepts and principles. Misconceptions about the concept of chemical equilibrium summarized from the literature are below;

1. The essence of the chemical equilibrium concept (Bergguist and Heikkinen, 1990; Hackling and Garnett, 1985; Wheeler and Kass, 1978).
2. The rate of the forward reaction increases when reaction approaches to equilibrium (Niaz, 1998; Hackling and Garnett, 1985).

3. The constancy of equilibrium constant (Voska and Heikkinen, 2000; Wheeler and Kass, 1978).
4. Left and right sidedness (Gorodetsky and Gussarsky, 1986).
5. At equilibrium, the concentration of reactants are equal to the concentration of product (Hackling and Garnett, 1985).
6. Failure to distinguish between rate and extent of reaction (Banerjee and Power, 1991; Gorodetsky and Gussarsky, 1986; Hackling and Garnett, 1985; Wheeler and Kass, 1978).
7. Assuming that forward reaction goes to completion before the reverse reaction starts (Niaz, 1998; Hackling and Garnett, 1985; Wheeler and Kass, 1978).
8. Misuse of LeChatelier Principle (Voska and Heikkinen, 2000; Quilez and Solaz, 1995; Banerjee and Power, 1991; Gorodetsky and Gussarsky, 1986; Hackling and Garnett, 1985).
9. The effect of a catalyst (Voska and Heikkinen, 2000; Quilez and Solaz, 1995; Banerjee and Power, 1991; Gorodetsky and Gussarsky, 1986; Hackling and Garnett, 1985).
10. Competing equilibria (Voska and Heikkinen, 2000; Gorodetsky and Gussarsky, 1986).

Teaching programs are looked at to classify and point out the sequence of suggestions that would help in understanding chemical equilibrium and application of the Le Chatelier's principle. According to Finster (1992), researchers have pointed out methods of instruction that teach students to build an understanding of chemical equilibrium laws of chemistry that improves their problem and their understanding of concepts (Finster, 1992). This study aims to identify students' misconceptions regarding chemical equilibrium concepts. It is expected that this study could assist teachers to develop and evaluate new methodologies, arrange problem-solving experiences for students' learning and identify students as being either conceptual or algorithmic problem solvers.

Method

Subjects

In this study, 216 11th grade students taking chemistry courses from four different high schools were enrolled after their formal instruction.

Instrument

Garnett and Hackling (1984) developed and applied a misconception identification test to 30 10th grade chemistry students. The reliability coefficient of the test was found to be 0.82. The test included 47 multiple choice and true-false items which are related to chemical equilibrium concepts classified in 4 categories; 1. Approach to equilibrium, 2. Characteristics of equilibrium, 3. Changing equilibrium conditions, 4. Addition of a catalyst. Multiple choice items consisted of one correct answer with the distractors reflecting students' misconceptions regarding chemical equilibrium. This test was translated into Turkish by the researchers. The test was administered to 216 11th grade high school students after their formal class schedule to diagnose students' misconceptions in the classified categories. The reliability coefficient of the test was found to be 0.87.

After administration of the test, 20 students having high, medium and low scores on the test were selected for interview in order to understand their reasoning about the items.

Analyses

The data were analysed by using the SPSS (Statistical Packages for Social Sciences) program. For each item, the percentages of each alternative, which students selected, were computed using descriptive statistics.

Results

Students were supposed to answer all the questions in the test through using the following reaction:

$$2NO_{(g)} + Cl_{2(g)} \rightleftarrows 2NOCl_{(g)} + \text{heat}$$

Generally, the answers indicate widespread misconceptions among students in topics related to: approaching equilibrium, characteristics of equilibrium, changing equilibrium conditions and adding a catalyst. The common misconceptions found are summarized in Table 1.

Misconception 1, related to approaching equilibrium, showed that 39% of the students thought that the total decrease in concentrations of NO and Cl2 is equal to the increase in concentration of NOCl. From the interviews, it was seen that students might have used the law of conservation of mass to predict the changes in concentrations of reactants and products when the

Table 1.
Percentage of students' misconceptions in chemical equilibrium concepts (%)

Students' misunderstanding	*percentage*
I. Approach to Equilibrium	
1. When approaching to equilibrium, the decrease in concentrations of NO and Cl2 is equal to the increase in concentration of product	39
II. Characteristics of Equilibrium Conditions	
2. At equilibrium, the concentrations of reactants and product change with time.	22.9
3. At equilibrium, the concentrations of reactants and product are equal.	35.5
4. At equilibrium, the concentration of NO equals the concentrationof NOCl	35.5
5. At equilibrium, as the reaction oscillates between forward and reverse, concentrations of reactants and product change continuously	50.6
6. At equilibrium, the rates of forward and reverse reactions are equal but not constant	34.4
7. At equilibrium, the rates of forward and reverse reactions are not equal	39.8
III. Changing Equilibrium Conditions	
A. After equilibrium is achieved, [NO] is instantaneously increased at constant temperature and volume.	
a) Effect on concentration when equilibrium is reestablished	
8. [Cl_2] becomes greater than its initial equilibrium value	22.1
b) Initial effects on rates of reactions	
9. The rate of reverse reaction decreases instantaneously	48.9
10. The rate of forward reaction becomes less than the rate of reverse reaction	22.1
c) Effect on reaction rate when the equilibrium is reestablished	
11. The rates of forward and reverse reactions become equal to their initial equilibrium value	53.2
B. After equilibrium is achieved, temperature of the system is instantaneously increased at constant volume.	
a) Effect on concentration when equilibrium is reestablished	
12. [NO] and [Cl_2] becomes less than its initial equilibrium value	25.5
13. [Cl_2] becomes equal to its initial equilibrium value	26.4
14. [NOCl] becomes greater than its initial equilibrium value	35.9
b) Initial effects on rates of reactions	
15. The rate of forward and reverse reactions instantaneously decreases	30.8
16. The rate of forward reaction becomes greater than the rate of the reverse reaction	50.6
c) Effect on reaction rate when the equilibrium is reestablished	
17. The rates of forward and reverse reactions become equal to their initial equilibrium value	45.9
d) Effect on equilibrium constant when equilibrium is reestablished	
18. Equilibrium constant becomes greater than its initial equilibrium value	21.6
19. Equilibrium constant becomes equal to its initial equilibrium value	43.7
C. After equilibrium is achieved, volume of the system is decreased at constant temperature.	
a) Effect on concentration	
20. The concentrations of all species instantaneously decrease	26.8
21. When the equilibrium is reestablished, [NO] and [Cl_2] becomes greater than the adjusted value.	39.6
22. When the equilibrium is reestablished, [NOCl] becomes less than the adjusted value	24.2
b) Initial effects on rates of reactions	
23. The rate of forward and reverse reactions instantaneously decreases	31.6
24. The rate of forward reaction becomes less than the rate of reverse reaction	26.8
c) Effect on reaction rate when the equilibrium is reestablished	
25. The rates of forward and reverse reactions become equal to their initial equilibrium value	43.3
d) Effect on equilibrium constant when equilibrium is reestablished	
26. The value of equilibrium constant becomes greater than its initial equilibrium value	20.3
IV. Effect of Catalyst	
After equilibrium is achieved, a catalyst is added to the system at constant temperature, pressure and volume.	
a) Effect of concentration	
27. [NO], [Cl_2] and [NOCl] become greater or less than their initial equilibrium value depending on the effect of catalyst	31.2
b) Effects on rates of reactions	
28. The rate of forward and reverse reactions becomes either unchanged or increased depending on whether the catalyst favours the forward or reverse reaction	40
c) Effect on equilibrium constant when the equilibrium is reestablished	
29. The equilibrium constant becomes greater or less than its initial equilibrium value depending on the effect of catalyst	25.1

system is approaching equilibrium. This law states that the total mass of substances does not change during a chemical reaction; the number of substances may change but the total amount of matter remains constant. Similarly, students may think that the total decrease in concentrations of reactants is equal to the total increase in the concentration of product as the system is approaching equilibrium.

Misconceptions 2, 3, 4, 5, 6 and 7 were related to characteristics of chemical equilibrium, the percentages of the misconceptions were found to be 22.9, 35.5, 35.5, 50.6, 34.4, and 39.8, respectively. The interviews indicated that students could not understand the dynamic nature of equilibrium. They cannot acquire reversibility of reactions, they think reactions are one way, and they may make a simple arithmetic relationship between the concentrations of reactants and products. The common misconceptions in this category were that the concentrations of reactants and product are equal, the concentration of NO equals the concentration of NOCl, as the reaction oscillates between forward and reverse, concentrations of reactants and product change continuously and the rates of forward and reverse reactions are equal but not constant.

Misconceptions 8, 12, 13, 14, 20, 21, 22 were related to the effects of changing concentration, temperature and volume on concentrations when equilibrium was re-established. For this category, 22,1 % of students responded that [Cl2] becomes greater than its initial equilibrium value when equilibrium is re-established following an increase in the concentration of NO. Interview results showed that students could not comprehend the relationship between consumption of reactant and formation of product in a chemical reaction. 25,5, 26,4 and 35,9 % of the students showed misconceptions for 12, 13, and 14 in Table 1, respectively. It was seen from the interviews that students could not explain the change in concentration of reactants and product when the equilibrium is re-established following an increase in the temperature. Neither could they compare initial and final equilibrium situations.

Most students think that an increase in the temperature increases the kinetic energy of molecules which react more rapidly to form more product without considering whether the reaction is exothermic or not. Moreover, they misuse Le Chatelier's principle. 26,8, 39,6 and 24,2 % of the students hold misconceptions for 20, 21 and 22 in Table 1, respectively. Interview results revealed that students could not explain the change in concentration of reactants and product when the equilibrium is re-established following a decrease in volume. Students could not relate volume correctly with concentration for misconception 20. Students could not make a reasonable interpretation about the relationship between concentration and volume due to their inadequate knowledge.

Misconceptions 9, 10, 15, 16, 23, 24 were related to the initial effects of changing concentration, temperature and volume on the rate of reactions. The percentages were found to be 48,9, 22,1, 30,8, 50,6, 31,6 and 26,8, respectively. Interview results indicated that some of the students explained misconception 9 by saying that the rate of the forward reaction increases because the reaction tends to decrease the excess of NO and the rate of reverse reaction decreases because there is already excess NO. Some students explained their reasoning for misconceptions 15 and 16 without considering whether the reaction is exothermic or not. Most of students who participated in the interviews did not give a reason for their misconceptions 23 and 24. Misconceptions 11, 17 and 25 were about the effect on reaction rate when the equilibrium was re-established. The percentages were found to be 53,2, 45,9 and 43,3, respectively. The majority of students in the interviews could not compare the rates of reactions when equilibrium was re-established with those at the initial equilibrium. They believed that the rates would be the same as the initial equilibrium. Misconceptions 18, 19, 26 were concerned with the effects of changing temperature and volume on the equilibrium constant. 21.6, 43,7 and 20,3 % of the students hold misconceptions for 18 and 19 in Table 1 respectively. The effects of changing concentration on equilibrium constant was not counted in this study because students showed less than a 20 % misconception rate in this category. At the interview, most students explained their reasoning for misconception 18 in this way: when we increase the temperature, the reaction shifts in the forward direction and thus the equilibrium constant increases. However, they did not pay attention to how the direction of a reaction changes in an exothermic reaction. Also, most students explained their reasoning for misconception 19 as an effect of changing concentration. They explained their reasoning for misconception 26 in the following way: when we decrease volume, the concentrations of reactant and product increase and the reaction shifts in the forward direction where the number of moles is less than the number of moles on the reactant side. When the new equilibrium was re-established, the concentration of product is more than the concentration of reactant. This indicates that the students do not have enough knowledge of these concepts.

Misconception 27, 28 and 29 were related to the effect of adding a catalyst to concentrations of reactants and product with rates of reaction and equilibrium constant. 31.2, 40 and 25.1 % of students demonstrated misconceptions for 27, 28 and 29 in table 1, respectively. Most students in the interviews accounted for this as the effect of adding a catalyst which changes the way of reaction depending on favored with rate of forward or reverse reaction.

Discussion

The purpose of this study was to determine 10th grade students' misconceptions regarding chemical equilibrium concepts. The results showed that students hold a lot of misconceptions in the areas of approaching to equilibrium, characteristics of equilibrium, changing equilibrium conditions and adding catalysts. Interviews indicated that the reasons for these misconceptions might be rooted in inadequate knowledge and everyday experience. These findings support the findings of Voska and Heikkinen, 2000; Camacho and Good, 1989; and Hackling and Garnett, 1985.

This study supports the view that students' misconceptions should be identified together with their reasons. Information about students' reasoning is important in terms of developing teaching strategies to remove or to minimize the likelihood of occurrence. Bodner (1986) indicated that teaching and learning are not synonymous; we can teach and teach well without having the students learn. To promote concept building and remediate any misconceptions it is important to provide students with opportunities to verbalize their ideas. A constructivist approach provides theoretical framework for current research on concept formation, misconceptions and conceptual change in science.

Suggestions

For further study, researchers need to investigate effective methods based on students' prior knowledge in order to remove students' misconceptions and lead them towards an understanding of the scientific concepts. Teachers should be aware of students' misconceptions. They should use teaching approaches to identify these misconceptions and introduce teaching strategies to encourage conceptual change. However, it is difficult to remove misconceptions after they are integrated into the students' cognitive structure. Students often retain their existing ideas even after formal instruction (Niaz, 1998; and Kathleen, 1994). Cognitive conflict, concept maps and conceptual change texts are some techniques used for conceptual change.

On the basis of the experience and knowledge gained from this study, the following recommendations can be made for teaching chemical equilibrium concepts:

1. Teachers should emphasize the difference between one-way only and reversible reactions.
2. Teachers should simplify complex problems. Students should be encouraged to look for all possible factors that influence outcomes.
3. Teachers should create concrete analogies that show the dynamic nature of forward and reverse reaction occurring at the same rate and constant concentrations of reactants and products at the equilibrium. This is possibly one of the most difficult concepts for students to understand since molecules and atoms are not seen reacting in simultaneously forward and reverse reactions. This concept can be demonstrated by analogies and models.
4. Teacher education programs need to take account of student teachers' alternative conceptions because a teacher's approach of instruction has a great effect on students' learning process.

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